Passive Acoustic Methods for Tracking Marine Mammals Using Widely-Spaced Bottom-Mounted Hydrophones

Eva-Marie Nosal
Department of Ocean and Resources Engineering
University of Hawaii at Manoa
2540 Dole Street, Holmes Hall 405
Honolulu, HI 96822, USA
phone: (808) 956-7686 fax: (808) 956-3498 email: nosal@hawaii.edu

Award Number: N000140811142
http://www.soest.hawaii.edu/ore/faculty/nosal

LONG-TERM GOALS

The long-term goal of this project is to improve passive acoustic methods for tracking marine mammals, with primary effort dedicated to methods that use bottom-mounted hydrophones. When possible, tracking results are used to study marine mammal behavior and bioacoustics.

OBJECTIVES

The main objective of this project is to develop and implement methods to deal with two specific challenges associated with tracking marine mammals using widely-spaced bottom-mounted hydrophone arrays: (1) Multiple animals whose calls cannot be easily separated or associated, and (2) Insufficient receiver coverage, in which case standard time-of-arrival (TOA) tracking methods fail.

APPROACH

This project uses existing datasets to develop and apply the tracking methods. The main effort is directed toward data collected at Navy Ranges, with data from PMRF provided by S. Martin and data from AUTEC provided by D. Moretti. Other datasets that use bottom-mounted sensors are also be considered as they are available and appropriate. The main species of interest in these datasets are sperm whales, beaked whales, minke whales, and humpback whales. Most methods will be generalizable to other species.

Although the two main tracking challenges addressed by this project (insufficient receiver coverage and multiple animals) are not exclusive of one another, initial efforts focus on isolating the problems (by identifying periods in a datasets with only one problem, for example) and solving them separately. As the separate challenges are met, efforts will progress to the joint problem.

The first step in localization involves estimating either time of arrivals (TOAs) or time differences of arrivals (TDOAs) between hydrophones. In cases with stereotypical vocalizations that are separated in time, TOAs can be estimated by using a detector. A different detector is implemented for each vocalization of interest. To date, detectors for sperm whale clicks, minke whale boings, and beaked

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2010		**00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Passive Acoustic Methods for Tracking Marine Mammals Using Widely-Spaced Bottom-Mounted Hydrophones	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Hawaii at Manoa,Department of Ocean and Resources Engineering,2540 Dole Street, Holmes Hall 405,Honolulu,HI,96822**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

whale clicks have been implemented and used for this purpose. In cases with non-stereotypical vocalizations that overlap in time, in which detectors cannot be used to establish TOAs, TDOAs are estimated using cross-correlation methods (either on waveforms or spectrograms). This method is most commonly needed for humpback songs at PMRF.

Model-based tracking methods [Thode 2005; Tiemann et al. 2004; Nosal 2007] are used for tracking since they can account for depth-dependent sound speed profiles (particularly important as refraction becomes significant at long distances, such as on Navy ranges [Chapman 2004]) and since they can accurately model and make use of multi-path arrivals. Methods are implemented using a Bayesian framework to incorporate available *a priori* information (e.g. maximum possible swim speed), get error estimates on position, and improve performance in uncertain and fluctuating environments. In this framework, a three dimensional grid is created and the likelihood of an animal present is calculated for each grid point and time. Calculations are based on measured TOAs, modeled TOAs, estimated uncertainties, and any available a priori information. All methods are fully automated through MATLAB code.

Eva-Marie Nosal is the key individual participating in this work as the principal investigator and main researcher.

WORK COMPLETED

In FY10, the "general automated detector" developed in FY09 was improved, tested, and applied to several datasets. The detector traces contours in spectrograms and can automatically detect unknown and unexpected transients in large and unexplored datasets. Although it is not optimal for expected or known sounds (where matched filters or other tuned detectors perform much better), it has been useful as a "first sweep" for large volumes of data in which unknown or unpredictable sounds are be present.

It was established in FY09 that call association can be accomplished in the case of multiple animals by "tracing" slowly varying TDOA lines in scatterplots of TDOA vs TOA. In FY10, this call association method was completely automated. It was tested against manual extractions for sperm whales and beaked whales at AUTEC and is currently being integrated into tracking algorithms.

To allow multiple animal tracking, a method was developed to combine likelihood surfaces for TOAs/TDOAs corresponding to multiple animals. It has been tested on simulated data and is now being applied to real datasets. Figure 1 shows the output from this technique, where 3 animals immediately evident.

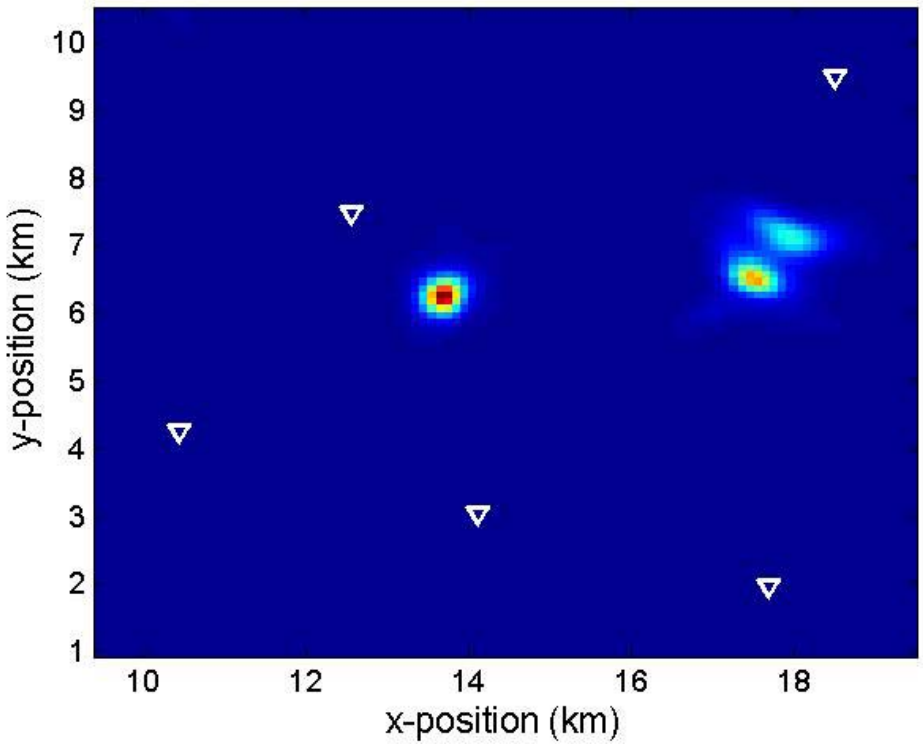

Figure 1. Likelihood surface for a multiple sperm whale dataset with red/blue showing areas of high/low probability of animal location. Triangles indicate AUTEC hydrophone positions. 3 animals are evident in this surface.

A beaked whale click detector was implemented for use in establishing TOAs for tracking beaked whales in the subset of the AUTEC/BRS dataset supplied by D. Moretti. Detected clicks have been associated using the TDOA association method described above, and ongoing effort aims to carefully determine 3D animal tracks.

RESULTS

Model-based tracking capabilities have been extended to include multiple animal datasets by developing a method that combines likelihood surfaces corresponding to multiple time-of-arrival differences.

In multiple-animal datasets, calls can be separated and associated by tracing persistent TDOA vs TOA lines. A method to do this has been automated for use in tracking multiple animals. The methods works well in cases with animals that vocalize regularly and are well-spaced (such as with sperm whales). Application to beaked whales is possible but more difficult since multiple closely spaced animals with short inter-click intervals and intermittent detections (due to the high directionality of beaked whale clicks) create considerable clutter in the scatterplot and poorly defined sampled TDOA lines.

Beaked whales have been added to current tracking capabilities by implementation of a beaked whale click detector. It is used for establishing TOAs for the localization methods and is being applied with the multiple animal model-based tracker to a subset of the AUTEC/BRS data.

IMPACT/APPLICATIONS

The the localization and tracking methods developed in this project will be useful for monitoring and studying marine mammal bioacoustics and behavior in the wild. Tracking results can be used to establish detection ranges and calling rates that are critical in density estimation applications. Methods developed to track marine mammals are useful for sources other than marine mammals (e.g. tracking of surface vessels can help to monitor fishing efforts in marine protected areas).

RELATED PROJECTS

ONR Award N000141010352: Passive acoustic tracking of minke whales.

ONR award N000140910489: The ecology and acoustic behavior of minke whales in the Hawaiian and Pacific Islands.

Preparation and planning for the 2011 DCL workshop, which will feature some of the data collected at PMRF in the localization dataset (as prepared by S. Martin).

REFERENCES

Chapman DMF (2004). You can't get there from here: Shallow water sound propagation and whale localization. *Can. Acoust.* 32(2), 167-171.

Nosal E-M, LN Frazer (2007). Sperm whale three-dimensional track, swim orientation, beam patter, and click levels observed on bottom-mounted hydrophones. *J. Acoust. Soc. Am.* 122(4), 1969-1978.

Thode A (2005). Three-dimensional passive acoustic tracking of sperm whales (Physeter macrocephalus) in ray-refracting environments. *J. Acoust. Soc. Am*. 18(6), 3575-3584.

Tiemann CO, MB Porter, LN Frazer (2004). Localization of marine mammals near Hawaii using an acoustic propagation model. *J. Acoust. Soc. Am.* 115(6), 2834-2843.

Wiggins SW and JA Hildebrand (2007). High-frequency acoustic recording package (HARP) for broad-band, long-term marine mammal monitoring. Proceedings of the IEEE Symposium on Underwater Technologies and Workshop on Scientific Use of Submarine Cables and Related Technologies, Tokyo, Japan, pp. 551-557.

PUBLICATIONS

Papers

Nosal E-M (2008). Flood-fill algorithms used for passive acoustic detection and tracking. Proceedings of the IEEE Workshop & Exhibition on New Trends for Environmental Monitoring using Passive Systems, Hyeres, France, ISBN: 978-1-4244-2816-8, IEEE Catalog Number: CFP08PSY-CDR [non-refereed, published].

Conference abstracts

Nosal, E-M (2009). Tetrahedral hydrophone array used to localize sperm whales. Proceedings of the 4th International Workshop on Detection and Localization of Marine Mammals using Passive Acoustics, Pavia, Italy, Sept. 2009.

Nosal E-M (2009). Tracking multiple sperm whales with widely-spaced bottom-mounted hydrophones. J. Acoust. Soc. Am., 125(4), p. 2588. Meeting of the Acoustical Society of America, Portland, OR, May 2009.